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D. Santos, O. Guillaudin, T. Lamy, F. Mayet, Emmanuel Moulin. MIMAC-He3: Micro-tpc MAtrix of Chambers of He3. 6th International Workshop on the Identification of Dark Matter, Sep 2006, Rhodes, Greece. pp.180-185. hal-00123276

**HAL Id: hal-00123276**

**<https://hal.science/hal-00123276>**

Submitted on 9 Jan 2007

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## MIMAC-He3 : Micro-tpc Matrix of Chambers of $^3\text{He}$

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The project of a micro-TPC matrix of chambers of  $^3\text{He}$  for direct detection of non-baryonic dark matter is outlined. The privileged properties of  $^3\text{He}$  are highlighted. The double detection (ionization - projection of tracks) will assure the electron-recoil discrimination. The complementarity of MIMAC-He3 for supersymmetric dark matter search with respect to other experiments is illustrated. The modular character of the detector allows to have different gases to get A-dependence. The pressure degree of freedom gives the possibility to work at high and low pressure. The low pressure regime gives the possibility to get the directionality of the tracks. The first measurements of ionization at very few keVs for  $^3\text{He}$  in  $^4\text{He}$  gas are described.

*Keywords:* Dark Matter, TPC, Helium-3, Spin-dependent interaction.

### 1. Introduction

Strong evidence in favor of the existence of non-baryonic dark matter arises from different cosmological observations. The cosmic microwave background (CMB) data [1,2] in combination with high redshift supernovæ analysis [3] and large scale structure surveys [4] seem to converge on an unified cosmological model [5]. The non-baryonic cold dark matter (CDM) would consist of still not detected particles, among those being the generally referred to as WIMPs (Weakly Interacting Massive Particles) the privileged ones. Among the different possible WIMPs, the lightest supersymmetric particle, in most scenarii, the lightest neutralino  $\tilde{\chi}$  predicted by SUSY theories with R-parity conservation, stands as a well motivated candidate. In the last decades, huge experimental efforts on a host of techniques in the field of direct search of non-baryonic dark matter have been performed [8–10,12]. Several detectors reached sufficient sensitivity to begin to test regions of the SUSY parameter space. However, Wimp events have not yet been reported. Besides the fact that the cross section could be very weak,

the energy threshold effect combined with the use of a heavy target nucleus leads to significant sensitivity loss for relatively light WIMPs ( $6 \text{ GeV} \leq M_{\tilde{\chi}} \leq 40 \text{ GeV}$ ).

As reported elsewhere [13,15,16], the use of  $^3\text{He}$  as a target nucleus is motivated by its privileged features for dark matter search compared with other target nuclei. First,  $^3\text{He}$  being a spin 1/2 nucleus, a detector made of such a material will be sensitive to the spin-dependent interaction, leading to a natural complementarity to most existing or planned Dark Matter detectors ( $\nu$  telescopes, scalar direct detection as well as proton based spin-dependant detectors). In particular, it has been shown [17,18] that an  $^3\text{He}$  based detector will present a good sensitivity to low mass  $\tilde{\chi}$ , within the framework of effective MSSM models without gaugino mass unification at the GUT scale [6,7].

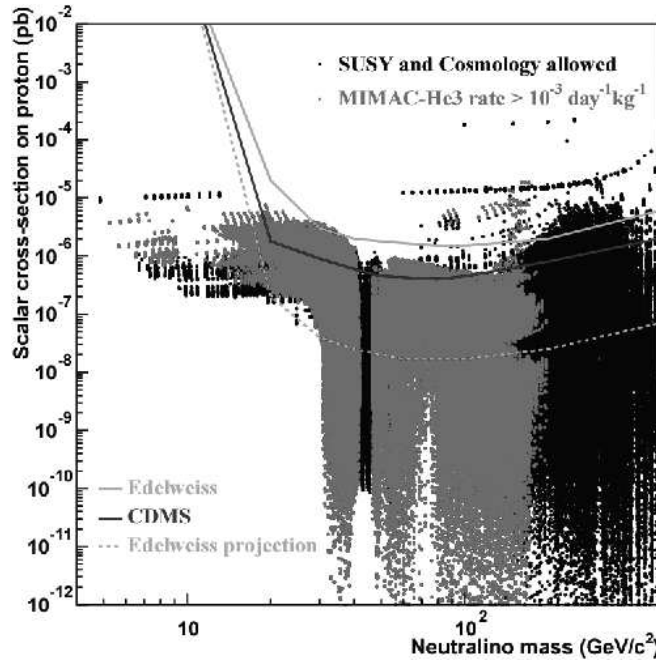
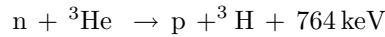


Fig. 1. SUSY non minimal models, calculated with DarkSusy code [7]. In grey the models giving an axial cross section ( $\tilde{\chi} - ^3\text{He}$ ) higher than the exclusion plot of MIMAC- $^3\text{He}$  with 10kg [18]. These models are compared with exclusion plots of scalar experiments and their projections. There are models, in grey, that will be very difficult to get with only a scalar approach.

The  $^3\text{He}$  presents in addition the following advantages with respect to other sensitive materials for WIMPs detection :

- a very low Compton cross-section to gamma rays, two orders of magnitude weaker than in Ge :  $9 \times 10^{-1}$  barns for 10 keV  $\gamma$ -rays
- the neutron signature made possible by the capture process :



Indeed it allows for an easy discrimination with  $\tilde{\chi}^0$  signal ( $E \lesssim 6$  keV). This property is a key point for Dark Matter search as neutrons in underground laboratories are considered as the ultimate background.

Any dark matter detector should be able to separate a  $\tilde{\chi}$  event from the neutron background. Using energy measurement and electron-recoil discrimination, MIMAC-He3 presents a high rejection for neutrons due to capture and multi-scattering of neutrons [20]. The MIMAC project propose a modular detector in which different gases ( $^3\text{He}$ ,  $\text{CF}_4$ ) can be used to have a dependence on the mass of the target. The  $^{19}\text{F}$  is other good target nucleus choice to have the axial interaction open, but proton based, increasing the attractiveness of the detector.

The MIMAC detector has two different regimes of work: i) high pressure (1,2 or 3 bar) and ii) low pressure (100 - 200 mbar). These two regimes allow us to have Wimp events at high pressure and search for correlation with the galactic halo apparent movement at low pressure. This last possibility should be validated with a special read out electronics as an important step of the project.

## 2. Micro-TPC and ionization-track projection detection

The micro time projection chambers with an avalanche amplification using a pixelized anode presents the required features to discriminate electron - recoil events with the double detection of the ionization energy and the track projection onto the anode. In order to get the electron-recoil discrimination, the pressure of the TPC should be such that the electron tracks with an energy less than 6 keV could be well resolved from the recoil ones at the same energy convoluted by the quenching factor. The electrons produced by the primary interactions will drift to the amplification region (mesh) in a diffusion process following the well known distribution characterized by a radius of  $D \simeq \lambda \sqrt{L[\text{cm}]}$  where  $\lambda$  is typically  $200 \mu\text{m}$  for  $^3\text{He}$  at 1 bar and  $L$  is the total drift in the chamber up to the mesh. This process has been simulated with Garfield and the drift velocities estimated as a function of the pressure and the electric field. A typical value of  $26 \mu\text{m}/\text{ns}$  is obtained for

1 kV/cm in pure  $^3\text{He}$  at a pressure of 1 bar. To prevent confusion between electron track projection and recoil ones the total drift length should be limited to  $L \simeq 15$  cm. It defines the elementary cell of the detector matrix and the simulations performed on the ranges of electrons and recoils suggest that with an anode of  $350\mu\text{m}$  the electron-recoil discrimination required can be obtained. The quenching factor is an important point that should be addressed to quantify the amount of the total recoil energy recovered in the ionization channel. No measurements of the quenching factor (QF) in  $^3\text{He}$  have been reported. However, an estimation can be obtained applying the Lindhard calculations [11]. The estimated quenching factor given by Lindhard's theory for  $^3\text{He}$  shows up to 70 % of the recoil energy going to the ionization channel for 5 keV  $^3\text{He}$  recoil.

### 3. Source MIMAC

In order to measure the QF for  $^3\text{He}$  and  $^4\text{He}$  we have developed at the LPSC a dedicated facility producing very light ions at a few keV energies. This facility, called source MIMAC, incorporates an ECR ion source coupled to a Wien filter, selecting  $q/m$ , and a high voltage extraction going up to 50 kV.

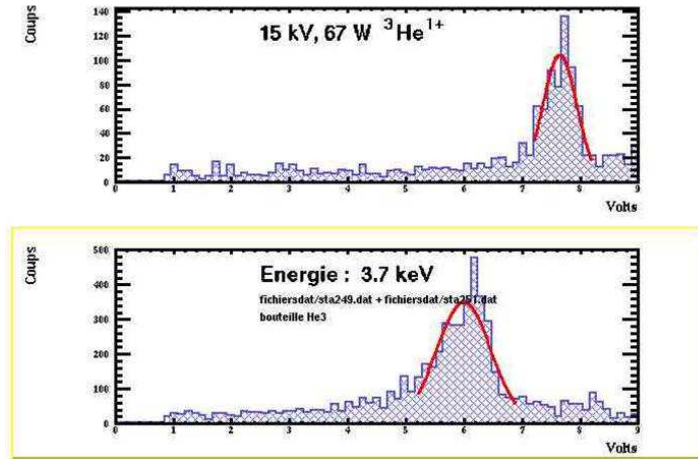


Fig. 2. Time of flight measurements performed with the MIMAC source. The figure shows the spectra at the two different positions (close to and far from the interface (source-chamber)) used to measure the  $^3\text{He}^+$  ions output energy when they have been accelerated at 15kV

The characterization of the output energies is made by a separate time of flight measurements as we can see on fig.2 for the case of  $^3\text{He}$  ions accelerated at 15 kV having a mean output energy of 3.7 keV. Using this facility we can explore the ionization at very low energies for  $^3\text{He}$  ions. We have measured by TOF, five output energies going from 13.7 keV up to 3.7 keV corresponding to five values from 30 to 15 kV of accelerating voltage extraction. Ionization measurements have been performed, with a standard micromegas grid in a gas chamber (95% of  $^4\text{He}$  and 5% of isobutane at 1 bar). A linear calibration fits very well the points measured and extrapolating to even lower voltage extraction, we can estimate the maximum output energy corresponding to 10.5 kV to 800 eV. On fig.3 the spectrum of the ionization left in the chamber by  $^3\text{He}$  at 800 eV is shown. On the same spectrum we show an internal conversion electron spectrum of  $^{57}\text{Co}$  during the two minutes the beam of  $^3\text{He}$  was on. This  $^{57}\text{Co}$  source will allow us to get an idea of the equivalent electron energies. We can differentiate on the spectrum the peak of ionization well separated from the electronic noise.

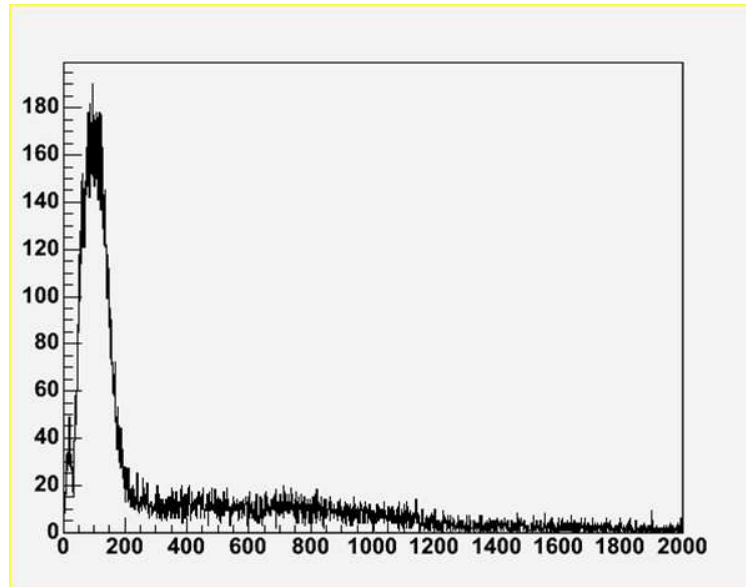


Fig. 3. A two minutes spectrum showing ionization peak corresponding to a beam, produced by the MIMAC source, of  $^3\text{He}$  at an energy estimated to 800 eV. An internal conversion source of  $^{57}\text{Co}$  spectrum is shown on the same spectrum. This source will help us to get the electron energy calibration for the QF measurement.

This spectrum shows clearly that we can expect to get the ionization left by  $^3\text{He}$  recoils in a chamber up to energies lower than 1 keV using the micromegas detector technology of our collaborators at Saclay [14].

The next steps will be to perform the QF measurements with the setup described above and to show the track of  $^3\text{He}$  recoils with a dedicated read-out electronics that is building up at our laboratory.

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